

34 Electromagnetic Therapy

A Primer

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INTRODUCTION

Electromagnetic (EM) signals are increasingly used in both systemic and local medical applications. We attempt here to provide an outline of the types of signals currently in use. This also necessitates a general introductory classification of EM signal types, based on how each signal varies in time.

Although EM medicine includes both diagnostic and therapeutic applications (Figure 34.1), the medical community is far more familiar with the former, especially with magnetic resonance imaging (MRI), electromyography (EMG), electroencephalography (EEG), electrocardiography (EKG), and magnetocardiography (MKG).

There are historical reasons for the medical unfamiliarity (even antipathy) with electromagnetically based therapies. One has only to look at the beginnings of modern medicine in the United States, specifically the 1910 Flexner report^{1,2} that provided the basis for medical education today. Prior to this report there was widespread use of electromagnetic techniques in medicine, often little more than late nineteenth century versions of snake oil cures. In great measure, the present aversion to electromagnetic therapies built into modern medicine is a direct result of Victorian age quackery. This century-old prejudice has carried though to today even as it becomes clearer that weak (low intensity) magnetic fields exhibit physiological effects that must be considered separately from those caused by high intensity fields. Although the effects related to exposures at large fields are, as a rule, readily explained by known physical interactions, usually Faraday induction or joule heating, the weak-field effects, often rather robust, remain mostly unexplained. This has unfortunately opened the door for many electromagnetic nostrums of dubious value.

A few of the examples we mention below illustrate the useful therapeutic delivery of heat by electromagnetic means.

The most interesting applications are, however, nonthermal. Further, we exclude from our discussion treatments that involve signals directly applied to specific regions of the body by subcutaneous means, such as pacemakers, defibrillators, deep brain stimulators (DBS), etc. Unlike electromagnetic applications, which are mostly unexplained, these represent techniques for replacing or enhancing faulty existing physiological electrical stimulations.

FIELD PARAMETERS

Whether one employs magnetic or electric fields, it is still necessary, when defining a given therapeutic procedure, to specify the waveshape, that is, how the signal develops in time. The question of waveshape can add greatly to the potential complexity that accompanies different electromagnetic applications. It is critical to realize that electromagnetic therapies are intrinsically far more complicated than pharmaceutical treatments. Many clinicians fail to appreciate this complexity, applying electric or magnetic fields as they would a pharmaceutical regimen whose outcome is solely dependent on titer. It is important to remember that there is no such thing as a little or a lot of magnetic field. For example, one can find high frequency signals that have miniscule intensity, low frequency signals with large gradients, or high intensity magnetic fields with low duty cycles. Each of these might produce different physiological responses and different therapeutic usefulness. The clinician must be aware of the various factors, or metrics, the sum of which is used to describe a given field.

One such factor relates to the vector nature of magnetic and electric fields. The characteristic of field uniformity has no analogue in pharmacy. Yet the interactive capabilities of a magnetic field are definitely a function of its uniformity. A

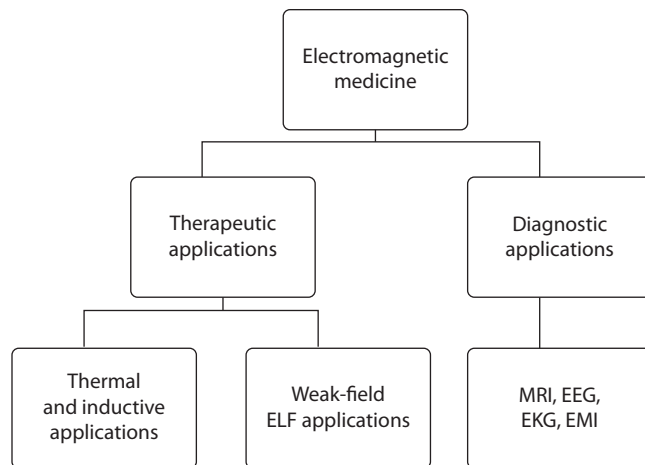


FIGURE 34.1 Clinical applications in electromagnetic medicine. Diagnostic applications are more acceptable than therapeutic and weak-field applications are less acceptable than thermal and inductive.

uniform field is one that has the same intensity and direction everywhere over the region in question. As a rule, this is a very difficult condition to maintain in any given application. Figure 34.2 compares the lines of force in a uniform field to those in one that is very nonuniform.

In laboratory practice, specially designed coils (e.g., Helmholtz or Merritt coils) are often used to maintain a certain degree of magnetic field uniformity within the active volume of application. However, it is usually the case that the volume within which uniform field conditions are actually achieved is but a small fraction of the total volume enclosed by the coils. One notable exception to this is found when using a properly designed solenoid (Figure 34.3).

It can be taken as a rule of thumb that none of the devices actually used for electromagnetic therapy achieve any degree of field uniformity over the treatment volume. This is especially true for field applications that utilize permanent magnets. Further, considering the wide range of dimensions and designs, it is very likely that no two therapeutic devices are strictly the same when considering the fields that are used.

One important classification of therapeutic EM signals is based on how the applied signal varies with time. These can be grouped into DC signals, trains of sine wave signals, and a wide variety of repetitively applied pulses. Signal trains can take on various forms, as shown in Figure 34.4. Signal intensity can be measured in different ways depending on the parameter that is considered essential to the therapeutic application, for example, voltage, current, and magnetic field intensity. These are, in turn, expressed in terms of specific units such as volts, millivolts, milliamperes, microamperes, microtesla, milligauss, etc.

SINE WAVES

Of the various time-varying signals utilized in EM therapeutic applications, the sine wave shape is the simplest to deal with and the easiest to generate (Figure 34.5). The frequencies

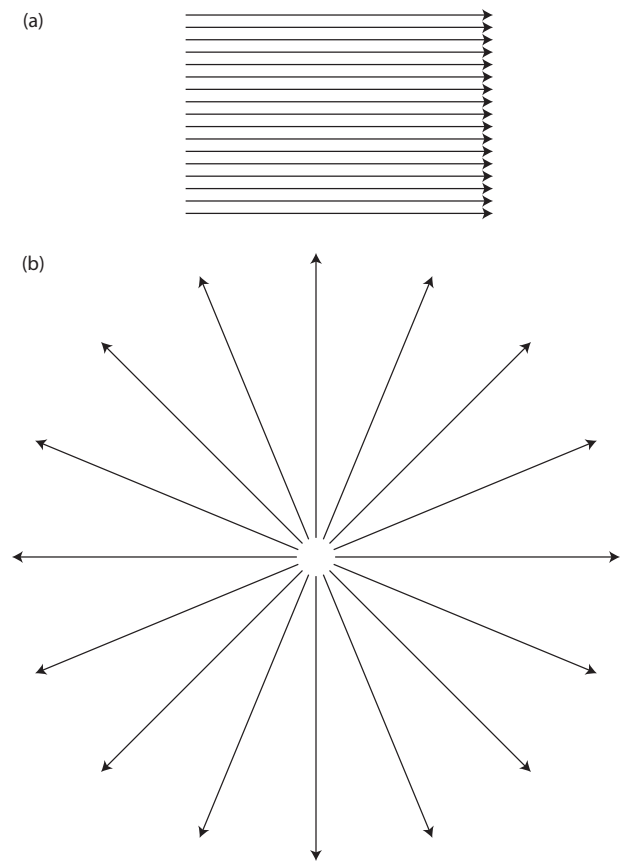


FIGURE 34.2 (a) A uniform field (electric or magnetic) is one in which everywhere within the region of interest there is the same intensity and direction. (b) Example of a very nonuniform electric field, namely that produced by a single positive charge. The lines of force drawn here are shown in two dimensions but in reality should always be thought of as three-dimensional. Thus, the lines of force in (b) are not only in the plane of the page but also point upwards and downwards.

of sine wave signals used in EM therapy can be ultralow, to about 1 Hz, and extend upwards to 50 GHz or more (1 GHz equals 1×10^9 Hz). At the lower extreme, a number of clinical applications utilize the extremely low frequency (ELF) region, which includes frequencies up to 300 Hz. These

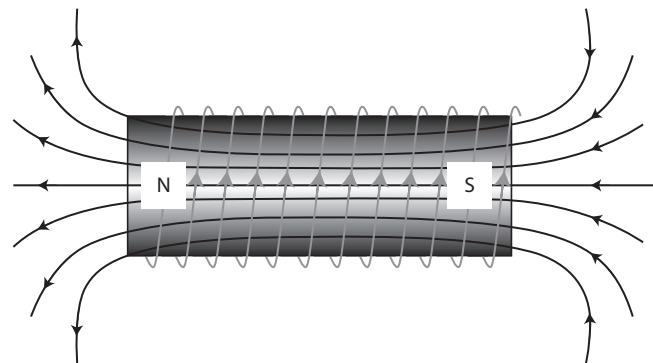


FIGURE 34.3 Excellent field uniformity is achieved inside a solenoid that is much longer than its diameter, say by a factor of seven or greater.

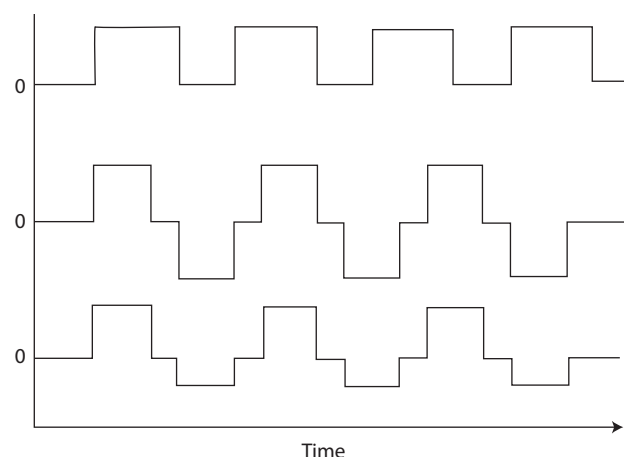


FIGURE 34.4 Three different pulse trains. The pulses at the top are monopolar, all positive. The lower two sets are bipolar, such that in each cycle both polarities are obtained. The bottom set of bipolar pulses show that positive and negative amplitudes need not be the same.

frequencies appear to be physiologically interactive, presumably because they couple to processes in the body that naturally occur at similar frequencies. Additionally, living tissue is transparent, not only to static (DC) magnetic fields, but also to ELF magnetic fields. Further, in some cases the ELF therapeutic application has been designed to take advantage of the easily available (and reliably constant) power line frequency, which, depending on the region, is either 50 or 60 Hz.

At higher frequencies, choices are limited to those permitted by the Federal Communications Commission (FCC) to avoid interfering with existing broadcast frequencies. Three such allowed frequencies are 13.56, 27.12, and 40.68 MHz (1 MHz equals 1×10^6 Hz). A number of EM therapeutic devices utilize the 27.12 MHz frequency. Needless to say, there is nothing biologically interesting about these specific frequencies. They are used solely because they are available!

Because sine waves are easiest to generate, these shapes have found extensive use in the design and implementation of electromagnetic therapy devices. This is especially true for those devices that are strictly electric in character, where signals are delivered through electrodes. Electrically based therapies can be more straightforward compared to magnetic applications operating at the same frequencies, because magnetic interactions can readily result in different effects in tissue, especially for higher frequencies and intensities.

Additionally, the medical community is more at ease with electrical applications in clinical procedures, even to the point where magnetic therapies are often viewed suspiciously.

Apart from the limited education of the average American doctor in the physical sciences, this suspicion of electromagnetic medicine closely follows the fact that no reasonable explanation has yet been found to explain those observations showing that therapeutic benefit does indeed result from specific applications of certain electric and/or magnetic signals.

A good example of a clinical application that utilizes sine wave signals that are purely electrical in nature is found

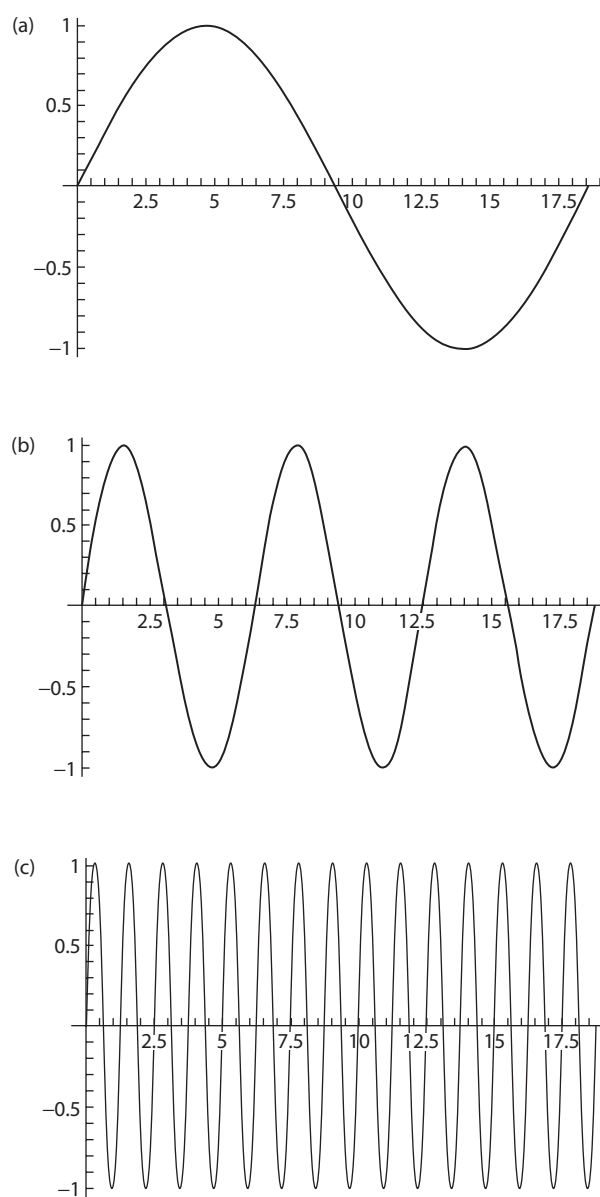


FIGURE 34.5 Three sine wave signals differing in frequency, but each having the same amplitude of 1.0 and plotted over the same 18 s time span. Frequencies are (a) 0.053 Hz, (b) 0.159 Hz, and (c) 0.79 Hz.

in the tumor-treating fields (TTF)^{3,4} used to fight cancer in devices designed by the Novocure Corporation (Portsmouth, NH, USA). Distinctly nonthermal signals, ranging between 100 and 200 kHz, are applied to the body using skin electrodes supplied by portable battery-powered generators, allowing patients freedom of movement even away from the hospital environment (Figure 34.6). This treatment covers a range of illnesses, including brain and lung cancer, and, in a number of instances, is Food and Drug Administration (FDA) approved.

Many therapeutic applications utilize signal shapes that, although based on sine waves, are somewhat more complex. Three such shapes are those that are modulated, rectified, and biased signals (Figures 34.7 through 34.10).



FIGURE 34.6 As a treatment for glioblastoma, the portable Novocure device supplies sine wave signals at frequencies ranging from 100 to 200 kHz to electrodes on the scalp.

An example of a procedure that uses modulated electrical sine waves (Figure 34.7) to treat liver cancer is found in the TheraBionic device (Mountain Brook, AL, USA).⁵ The clinically effective frequencies, varying sequentially between 100 Hz and 21 kHz, are applied by means of a 27.12 MHz carrier signal. One rather unique aspect of this treatment is the electrode arrangement, one of which, spoonlike, is located sublingually (Figure 34.8).

In AC interferential therapy (Figure 34.9) electrodes are used to apply two separate AC signals with slightly different

frequencies to the tissue in question, thereby creating a means for treating tissue with a low frequency electric current that may be difficult to achieve if applied directly. Rectified wave shapes of the form shown in Figure 34.10 for example are used in a device sold by the EMF Therapeutics Corporation (Chattanooga, TN, USA).⁶ This operates at a frequency of 120 Hz, indicative of the fact that the base frequency before rectification is the power line delivery frequency of 60 Hz.

One can add a DC component (also called a bias) to any sine wave, thus shifting its zero point (Figure 34.11). This is the basis of magnetic therapies employing ion cyclotron resonance (ICR), also referred to as CMF (combined magnetic field).

In practice, the two components comprising this type of signal are often not applied directly as shown, but are instead obtained using two separate coils to generate superposed magnetic fields that are then added to give the same result. Another variation of ICR, termed ion parametric resonance, maintains the fundamental ICR relationship but in addition also fixes the ratio between the DC and AC values in the total signal. A number of therapies have been designed using ICR, with the oldest (from the 1980s) the FDA approved treatment for pseudarthroses⁷ (Figure 34.12).

FARADAY INDUCTION

Since the middle of the nineteenth century, it has been known that a changing magnetic field can induce an electrical potential in nearby conductors. A generalized way of looking at this is given in Figure 34.13. The actual principle says nothing about current, but rather, it is stated in terms of the electrical potential. We can readily extend this in living tissue to current, because tissues are relatively good conductors. The basis for a great number of magnetic therapy devices entails

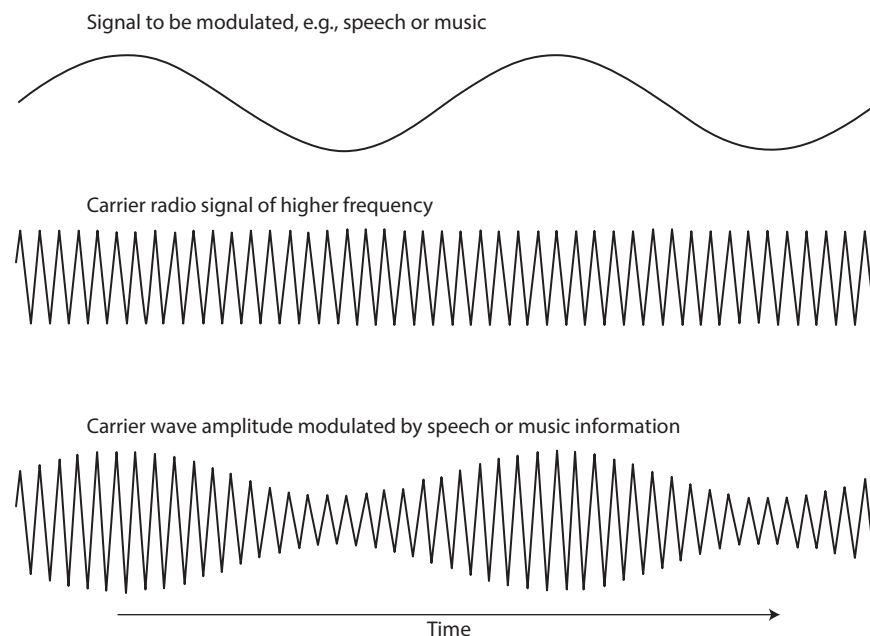


FIGURE 34.7 Adding a low frequency wave to a high frequency carrier wave results in the modulated signal below.

generating currents in tissue that is exposed to externally changing magnetic fields.

One of the pioneers in utilizing this concept in a clinical procedure was the orthopedist C. A. L. Bassett,⁸ who, with Pilla in the 1970s, designed a system that supplied pulses to nonunions, discontinuities in bone that are either congenital or fail to knit following fracture. This followed the discovery⁹ that subcutaneous application of small DC currents, on the order of microamperes, was capable of nonunion repair. Bassett was able to provide such currents to the defect non-invasively by making use of Faraday induction. This FDA approved procedure is still used, with the signal type universally referred to as PEMF, or pulsed electromagnetic field.



FIGURE 34.8 The fully portable TheraBionic device (Mountain Brook, AL, USA) uses a range of modulated radiofrequencies to treat liver cancer.

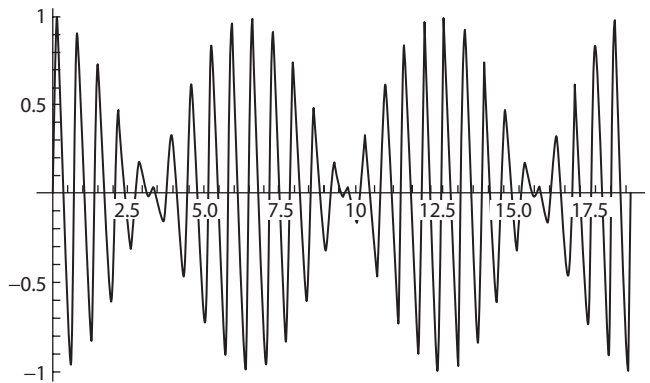


FIGURE 34.9 The phenomenon of “beats” is a special type of modulation, obtained when two sine waves equal in amplitude are added with frequencies close to each other. In this example, the original frequencies are 0.008 Hz apart.

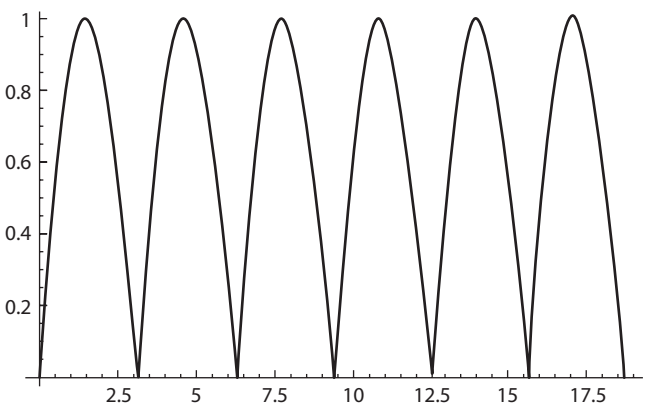


FIGURE 34.10 Rectified signal, as constructed from the sine wave shape given in Figure 34.5b. The negative parts of the original wave have been flipped, resulting in a signal that is everywhere positive. Note that the rectified signal repeats itself twice as fast as the original signal, such that the new frequency is now doubled to 0.32 Hz.

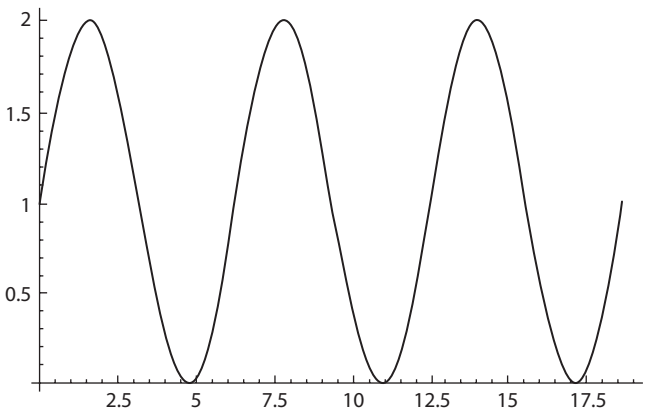


FIGURE 34.11 Example of a biased sine wave, obtained by adding a constant (DC) signal of one unit amplitude to the sine wave shown in Figure 34.5b. Pictured is only one very specific choice (1.0 units) for the added DC signal.



FIGURE 34.12 This Food and Drug Administration approved ion cyclotron resonance device manufactured by DonJoy to treat nonunions in bone is worn directly on the affected limb. Another version of this design is used as an adjunct to enhance spinal fusion.

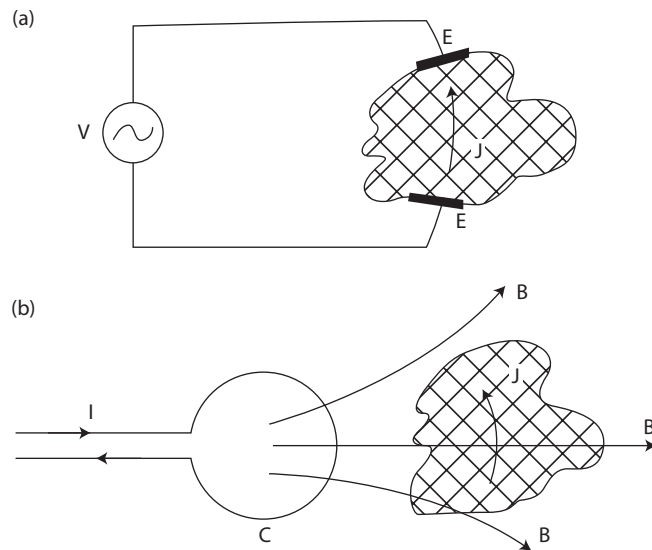


FIGURE 34.13 Electrical current J can be introduced into tissue in two ways, (a) by applying a voltage V through electrodes E (Ohm's Law), or (b) applying a changing magnetic field B from a coil C energized by a current I (Faraday induction). The change in field can occur if the current I is changing, or if there is relative motion between tissue and coil.

More recently, Faraday induction has been used in a different context, namely to induce currents in the brain (Figure 34.14), as a means of treating depression. The repetitive transcranial stimulation (rTMS) procedure^{10,11} is often compared with the older treatment for bipolar disorder, or electroconvulsive therapy (ECT), which is purely electrical in nature.

Although the means of delivery for rTMS is very different from Bassett's PEMF signals, and the focus is on the brain instead of the skeletal system, it is important to realize that Faraday induction is being employed in both cases. Both PEMF and rTMS are magnetic therapies whose utilization derives from inductively generated currents that were found earlier to be clinically efficacious when these were previously used in older, electrically based therapies.

PULSES

Pulses are signals that last for short lengths of time, often taking a square-like shape as in Figure 34.15. Although there are well recognized methods for analyzing any type of magnetic pulse, one can readily tell a good deal about the pulse by direct examination. The shorter the pulse, the higher the frequency content. One can say, for example, in very rough fashion, that microseconds-long pulses are equivalent to

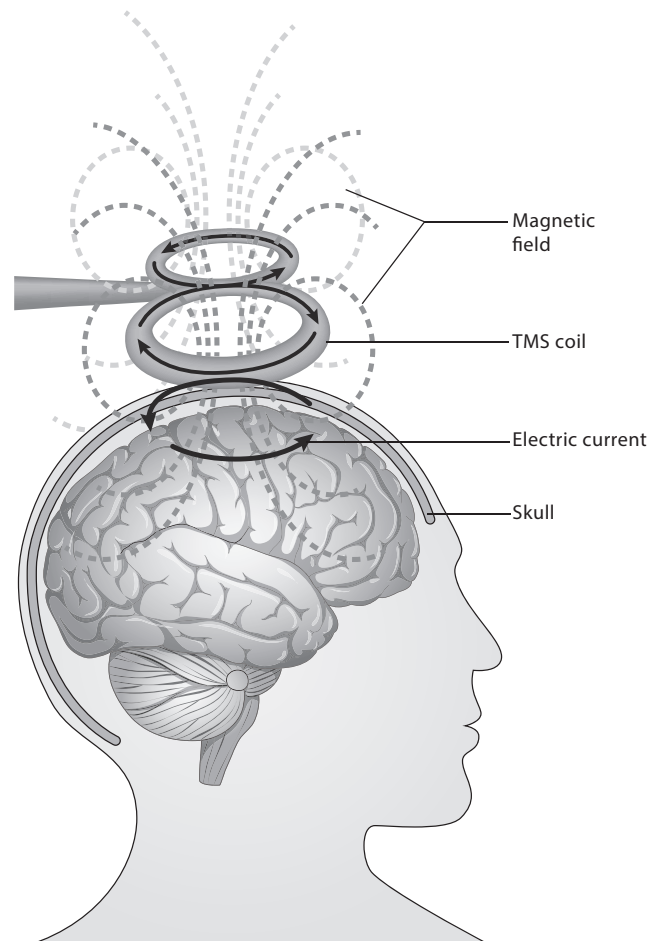


FIGURE 34.14 The repetitive transcranial stimulation coil (in a figure-of-eight configuration) is pulsed with very large currents to produce a rapidly changing magnetic field, thereby inducing currents in the brain.

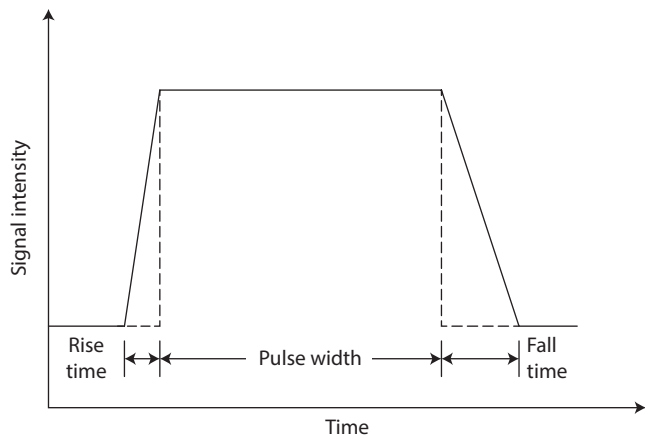


FIGURE 34.15 Typical square pulse, showing limitations on the electronics generation process that make it difficult to achieve very short rise and fall times.

frequencies on the order of MHz, while nanosecond pulses correspond to GHz frequencies. This follows from the mathematical breakdown of any pulse into its equivalent: the sum of sine waves of different frequencies, a process known as Fourier analysis. In this sense, pulses can always be described in terms of sine waves.

Pulses are very effective in generating high frequency currents in tissue. This follows the fact that very short magnetic signals represent a rapidly changing magnetic field, which in turn creates through Faraday induction a large degree of voltage change, or in tissue, a correspondingly large current that changes at the same rate. Yet another type of fast-changing magnetic signal that can be applied to tissue to induce an electrical change is found in the sawtooth shape, shown in Figure 34.16.

The sawtooth signal as externally applied in repetitive fashion is able to treat nonunions in bone because of the electrical waveshape that is induced within tissue as shown in Figure 34.17. The adjustable amplitude of this induced train of pulses is given in terms of the electric field and ranges from 1 to 100 mV/cm. In use, this pulse application is repeated periodically at repetition rates of 15 Hz or higher. This fact has led some to suggest that the rate of repetition

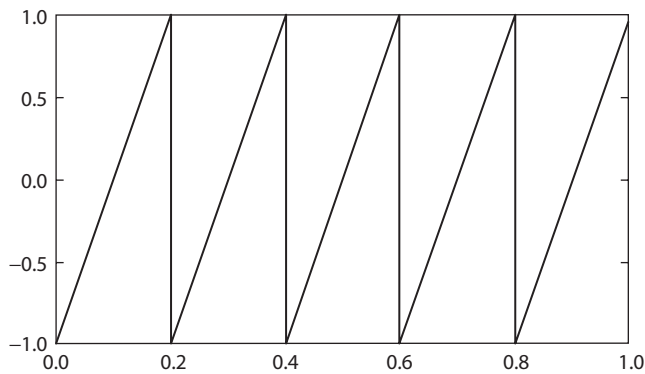


FIGURE 34.16 Example of sawtooth wave. Vertical axis in arbitrary units, for example, milligauss. Horizontal axis is time. For example, milliseconds.

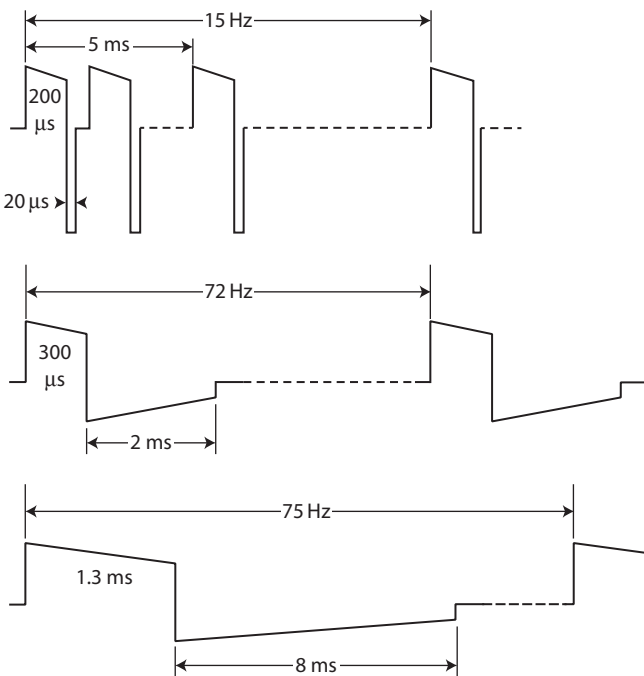


FIGURE 34.17 Train of electrical pulses induced in tissue by a sawtooth signal. Note that the pulsed electromagnetic field signal as shown here is applied repetitively, often at a 15 Hz rate.

itself may be of some consequence in assessing the reasons for the efficacy of treatment using PEMF devices, inasmuch as the repetition rates that are used fall within the ELF range.

A novel change in the way the PEMF signal is applied is shown in Figure 34.18, which illustrates the pulsed signal therapy (PST) approach¹² to magnetic therapy. Instead of a steady train of identical pulses, there is a random generation of successive pulses with different intensities and widths. This means that the tissues under treatment are exposed to a spectrum of

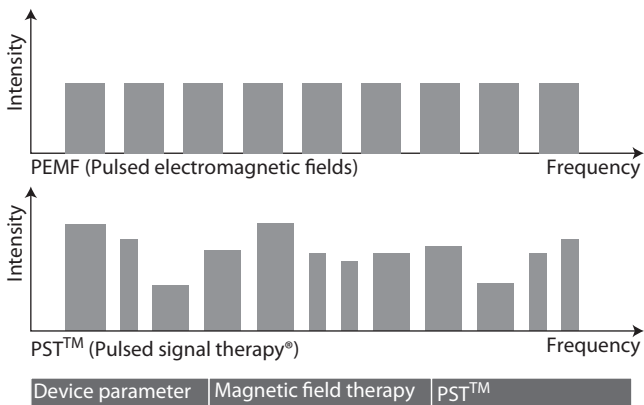


FIGURE 34.18 Comparison of the sequence of pulses in pulsed signal therapy (PST) therapy to the usual delivery of pulsed electromagnetic field signals. The upper pulse train is equivalent to what was shown in Figure 34.17. The lower, PST train consists of various heights (magnetic intensities) and widths (time spans). The different widths correspond to different frequency distributions, narrow widths implying higher frequencies and wider widths lower frequency groupings.

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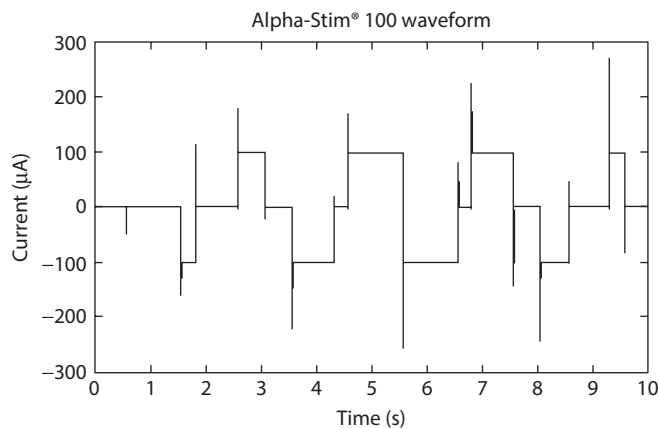


FIGURE 34.19 Electric pulse sequence applied during Alpha-Stim treatment. Pulses are bipolar with repetition rates of 0.5, 1.5, and 100 Hz, and currents developed range from 10 to 600 μA . Note the high frequency spikes at the leading and falling edges of each pulse, typically seen when pulses are switched on and off rapidly.

various magnetic intensities as well as more than one distribution of frequencies. This feature helps cover the problem that different patients with various medical histories may require differing types of electromagnetic treatment. In effect, it represents an attempt to cover all bases, an approach similar to what we have already seen in the TheraBionics therapy.

A bipolar equivalent to PST, one employing electrical pulses instead of magnetic, is found in the α -stim technology (Figure 34.19), is used to treat anxiety, depression, and insomnia.¹³ Electrodes directly attached to the scalp supply currents on the order of hundreds of microamperes directly to the brain. Yet another approach to treating the brain electrically for depression is found in transcranial direct current stimulation (tDCS),¹⁴ which applies milliamperes-level currents to the scalp.

The Seqex device (Pergine Valsugana, Italy; Figure 34.20) makes use of the ion cyclotron resonance physiological interaction,^{15,16} but in a totally different way from that shown in Figure 34.12 for treating bone disorders. Instead, the ICR signal characteristic is obtained by combining 30 magnetic field frequency distributions with the ambient vertical geomagnetic component, and then selecting that combination for which the tissue bioimpedance becomes anomalously low. In addition to this unique type of application, the Seqex technique represents a new, holistic approach to magnetic therapy, as the magnetic field application covers the patient's entire body. This device is currently being used clinically as an adjunct to chemotherapy and for treatment of neurological and musculoskeletal disorders.

THERMAL APPLICATIONS

For the most part, electromagnetic therapy is nonthermal in character, that is, not dependent on heat generated by the applied fields. However, there are exceptions to this rule. Figure 34.21 shows a typical pulse train generated for the purpose of diathermy treatment as manufactured by the Diapulse Corp (Great Neck, NY, USA). The 27.12 MHz signal is used to treat soft-tissue injuries.¹⁷ This approach clearly substitutes electromagnetic energy for the much older thermal treatments that directly applied heat packs to afflicted tissues.

Another, very different type of electromagnetic therapy is found in the Oncotherm device (Oncotherm GmbH, Troisdorf, Germany), which uses a modified version of hyperthermia to help destroy malignant tumors (Figure 34.22). A frequency of 13.56 MHz is used to treat a variety of cancers, including liver, brain, lung, pancreatic, breast, and prostate, among others.¹⁸ It has been estimated that upwards of 100,000 such treatments are conducted annually. By taking advantage of differences in cancerous and normal tissues, this therapy



FIGURE 34.20 The Seqex magnetic therapy device (Pergine Valsugana, Italy). One signal shape is selected from an array of 30 wave shapes, the choice depending on the whole-body impedance of the patient. This low frequency signal is repetitively applied by means of coils within specially designed pads that treat the entire body.

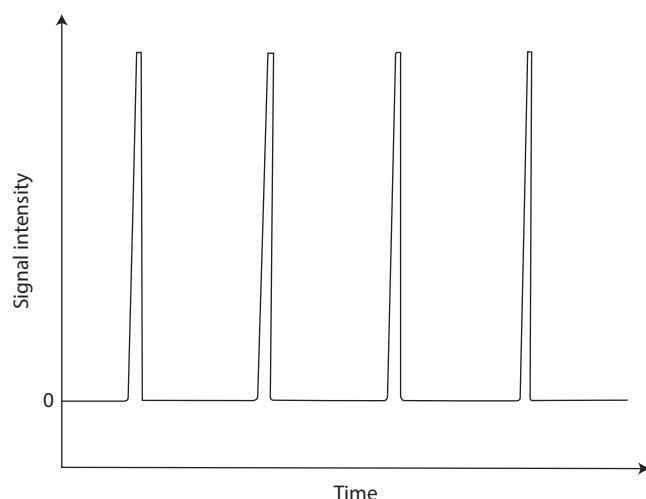


FIGURE 34.21 Illustrating the train of monopolar pulses used by Diapulse (Great Neck, NY, USA), applying the short microwave bursts that are used as a diathermy treatment. In this example the pulses are extremely short (about 65 μ s) and the time between pulses rather long (1600 μ s).

selectively overheats the tumor without affecting the surrounding normal tissue.

TRENDS

Many ELF magnetic interactions have been observed in the laboratory, but have yet to be clinically exploited. One excellent example is the ICR stimulus of cardiac stem cells that advances differentiation to the degree where successful regrowth of damaged heart muscle is now likely.¹⁹ In another case it has been found that low energy protein hydrolysis is possible using weak magnetic fields,²⁰ and, in follow-up studies,²¹ it has also been shown that resonance magnetic applications in mice brain can dissolve the β -amyloid plaque that is characteristic of Alzheimer's disease, and, further, that these

same ICR magnetic fields can significantly reduce cancer growth in mice.²²

Equally important, it is probable that future advances in electromagnetic medicine will follow the remarkable discovery²³ by Mikhail Zhadin that vanishingly small magnetic intensities are biologically interactive. This work represents the successful extension of ion cyclotron resonance interactions, already regarded as occurring at “impossibly small” μ T levels, to even smaller intensities in the nT range, down by a factor of 1000 times! This could have enormous consequences for clinical applications. Many of the therapeutic devices mentioned here may turn out to be even more efficacious when smaller intensities are used.

However, applications at these vanishingly small intensities are rather difficult. Proper use requires special shielding from local AC magnetic sources such as the omnipresent 60 Hz current-carrying wires in building walls, often presenting the researcher with laboratory fields greatly in excess of nanotesla intensities.

These advances and opportunities also have a dark side, providing new areas for quacks and charlatans that specialize in electromagnetic “cures” to prey on the sick. For example, we have already seen devices based on “picotesla stimulation” marketed without regard to the need to shield or correct for more intense, local magnetic fields. Electromagnets directly purchased from physics supply houses have been touted as “molecular energizers” to help combat brain cancer. Furthermore, in the longest-lived scam perpetrated on the sick and dying, the role of frequency in promoting wellness has been repeatedly misstated by some for more than 50 years.

The recognition of the importance of frequency in electromagnetic medicine that we have outlined here is a far cry from nonsensical claims that diseased cells can be “blown up” at certain frequencies, or that the entire array of human disease is traceable to specific parasites, each of which has its own unique susceptibility to a given frequency.

Unfortunately, we note that the recent successes obtained by “traditional” clinicians in using electromagnetic techniques, for example, Novocure, TheraBionic, to treat cancer have not carried over to their admitting that there is a profound puzzle connected to the full understanding of these therapies. They give inadequate explanations for the robust efficacies that are observed, using traditional bioengineering language that fails to explain how cells are actually affected. This lack of real explanation mirrors the experience of many laboratory researchers who repeatedly reported on electromagnetic effects in living systems, but discovered that their efforts were not considered credible without a reasonable explanation based in molecular biology. It is hoped that the clinical results will serve to provide greater credibility for those studying weak-field effects in less clinical settings.

It is a fact that resonance studies clearly indicate that living systems are sensitive to selected frequencies with observed efficacies, probably related to existing physiologic events involved in the various activation pathways one uses to describe pharmaceutical medicine.²⁴ Successful treatment resulting from application of a given frequency at a given

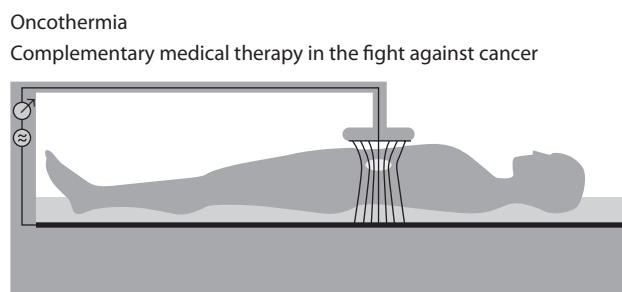


FIGURE 34.22 Schematic showing the basic way in which Oncotherm (Oncotherm GmbH, Troisdorf, Germany) treatments are conducted. High-voltage 13.56 MHz electromagnetic radiation is directed to the tumor, making use of the self-focusing that occurs because of the intrinsically higher conductivity of cancer cells. The patient lies on an electrode bed while the moveable upper electrode is deployed to computer-directed positions determined by the size and location of the tumor.

intensity appears to mimic the positive actions of otherwise prescribed biochemicals.

In short, it is our view that electromagnetic medicine functions as a substitute for the pharmacopeia.

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GLOSSARY

Angular frequency Usually symbolized as Greek letter ω . Related to linear frequency through the formula $\omega = 2\pi f$, measured in terms of rad/s (radians per second).

Athermal signal Same as nonthermal signal.

Beat(s) The new frequency that results from adding two sine waves of equal amplitude but slightly different frequencies. Equal to the difference between the two original frequencies. Sometimes called the *interference frequency* or *AC interference frequency*.

Bipolar signal Signal composed of both positive and negative components. Sometimes called *biphasic signal*.

CES Cranial electrical stimulation.

CMF Combined magnetic field, formed by adding DC magnetic field to sinusoidal magnetic signal. Same as ICR when appropriate values of DC magnetic field and AC magnetic frequency are used.

Constant current amplifier Electronic circuit that automatically adjusts the output voltage of a given power supply to maintain a constant current.

Current density Electrical current per unit cross-sectional area, measured, for example, in terms of microamperes per centimeter squared ($\mu\text{A}/\text{cm}^2$).

Duty cycle Measure of the energy supplied over a given length of time. Increases with the intensity of the pulsed signal and decreases with the increased time between pulses.

ECT Electroconvulsive therapy.

Electric field Measure of the electric field intensity. Often symbolized as E and specified in terms of V/cm, mV/cm, or V/m.

Electrostatic field An electric field that does not change in time.

EMF Two meanings: electromagnetic field, also (less used presently) electromotive force, an older term for electric potential difference.

Fall time Time interval over which a pulsed signal falls from its maximum value.

Faraday's Law of Induction A changing magnetic field can create an electrical potential difference. If this occurs in an

electrically conducting material, a current density results within the material.

Giga Prefix meaning one billion times, or 10^9 times larger, as in gigahertz or GHz.

GMF The geomagnetic field.

ICR Ion cyclotron resonance.

Helmholtz coil Parallel array of two circular coils connected in series-adding configuration where the separation between the coils is equal to the coil radius. Commonly used to obtain uniformity of field near the center of the array, along its axis.

Hertz (Hz) Measurement unit for frequency of sine wave or any periodic phenomenon. Appears often with appropriate prefix, for example, kHz, MHz, GHz.

Kilo Prefix indicating a factor of 1000 (10^3) larger as in kV, kG, and kHz.

Magnetic gradient A description of how much the magnetic field changes in any one direction, measured for example, in terms such as microtesla per meter ($\mu\text{T/m}$).

Magnetostatic field Magnetic field that does not vary in time.

Mega Prefix meaning one million times (10^6) larger, as in MHz.

Micro Written as Greek letter μ . Commonly used prefix in electromagnetic measurements, same as one millionth, or 10^{-6} , for example, μT , μA , μV . In biology, 1 μm (1 micron) is often used as a measure of distance.

Milli Prefix in electromagnetic measurements. Equals one thousandth (10^{-3}). for example, mT, mV, mA.

Modulated signal Result of adding two sinusoidal signals, usually with very different frequencies. The higher frequency signal is the carrier, and the lower signal, the modulation frequency.

Monopolar signal Signal that is always positive, sometimes called monophasic.

Nano Prefix meaning one billionth, or 10^{-9} times smaller, as in nV, nA, and nT.

Noise Unplanned variation in voltage or current signal that can result from random perturbations in electronic or electric components, mostly due to thermal effects.

Nonthermal signal Signal that does not result in increased temperature within tissue.

Observable Parameter used as a measure of a physical state, for example, magnetic field, voltage, current, temperature.

Oscillatory Same as periodic.

Parallel plate capacitor Pair of parallel electrical conducting plates where the diameter of each plate is much greater than the separation between the plates. Used to obtain highly uniform electric field between the plates.

PMF Pulsed magnetic field. Same as PEMF.

Peak value Maximum amplitude of sinusoidal signal.

Peak-to-peak value Total swing in signal intensity, measured from negative minimum of sine wave to maximum positive, or simply twice the peak value.

Pico Prefix meaning one million million times (10^{-12}) smaller, as in pV, pA, pT.

Pulsatile Same as pulsed.

Pulse height Maximum amplitude of pulse.

Pulse train Sequence of pulses in one cycle. Same as pulse burst.

Pulse width Interval of time over which a single pulse is applied.

PST Pulsed signal therapy.

Rectified signal Modified sine wave, always positive, either as half-wave rectification, skipping any original negative components, or full-wave rectification, where the originally negative parts of the wave shape are flipped up into the positive region.

Repetition rate Frequency, in cycles per second, (or Hz) with which a periodic signal repeats itself. Typically used to describe nonsinusoidal signals that are repetitive.

Rise time Time it takes for a pulsed signal to reach its maximum value.

rms value Root-mean-square of maximum intensity of sine wave. Equal to 0.7071 times the maximum amplitude of the sine wave. Same as effective (eff) value.

rTMS Rapid transcranial magnetic stimulation.

Sawtooth signal Waveform similar to saw blade, either rising slowly to a maximum and falling rapidly or rising rapidly and falling slowly.

Signature Same as waveform.

Solenoid Closely wound coil on long cylinder that can provide excellent field uniformity within the cylinder volume.

tDCS Transcranial direct current stimulation.

TENS Transcutaneous electrical nerve stimulation.

Transient A single pulse, usually nondescript and the result of a switching problem or unexplained perturbation such as a temporary loss of power or remote lightning stroke.

TTF Tumor treating fields.

Uniform field Electric or magnetic field that is everywhere within a given region constant in direction and intensity.

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